

A SYSTEM AND METHOD FOR COMPUTING THE LOCATION OF A MOBILE TERMINAL IN A WIRELESS COMMUNICATIONS NETWORK

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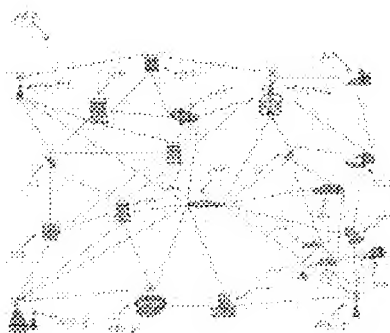
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Abstract of WO 03044986 (A1)

A system and method for computing the location of a mobile terminal (102) in a wireless communications network (100), such as an ad-hoc wireless communications network. In particular, the system and method estimates the location of a mobile terminal (102) in a wireless communications network (100), such as an ad-hoc terrestrial wireless communications network, based on estimated distances to a plurality of terrestrial reference terminals (104) using error minimizing techniques, such as those based on Gauss's postulate. In doing so, the system and method estimate a respective distance from the mobile terminal (102) from the reference terminals (104), calculate a respective simulated pattern (C1-C5), such as a sphere or circle, about each of the respective reference terminals (104) based on the respective distance from the terminal 102) to each respective reference terminal (104) and the respective locations of the respective reference terminals (104), estimates a location at which each of the simulated patterns (C1-C5) intersect each other, and identifies the estimated location as



representing the location of the
terminal (102).

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A SYSTEM AND METHOD FOR COMPUTING**1 THE LOCATION OF A MOBILE TERMINAL IN
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(+3) G01S5/14; (+10)**Publication info:** AU2002346385 (A1) — 2003-06-10**A SYSTEM AND METHOD FOR COMPUTING****2 THE LOCATION OF A MOBILE TERMINAL IN
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[US]**EC:** H04W64/00; G01S5/02R1; **IPC:** G01S5/00; G01S5/02;
(+3) G01S5/14; (+10)**Publication info:** CA2466588 (A1) — 2003-05-30**A SYSTEM AND METHOD FOR COMPUTING****3 THE LOCATION OF A MOBILE TERMINAL IN
A WIRELESS COMMUNICATIONS NETWORK****Inventor:** BELCEA JOHN [US] **Applicant:** MESHNETWORKS INC
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A SYSTEM AND METHOD FOR COMPUTING**4 THE LOCATION OF A MOBILE TERMINAL IN
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A SYSTEM AND METHOD FOR COMPUTING**5 THE LOCATION OF A MOBILE TERMINAL IN
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[US]**EC:** H04W64/00; G01S5/02R1; **IPC:** G01S5/00; G01S5/02;
(+3) G01S5/14; (+10)**Publication info:** KR20050044508 (A) — 2005-05-12**System and method for computing the****6 location of a mobile terminal in a wireless
communications network****Inventor:** BELCEA JOHN M [US] **Applicant:** MESHNETWORKS INC
[US]**EC:** H04W64/00; G01S5/02R1; **IPC:** G01S5/00; G01S5/02;
(+3) G01S5/14; (+11)**Publication info:** US6728545 (B1) — 2004-04-27**A SYSTEM AND METHOD FOR COMPUTING****7 THE LOCATION OF A MOBILE TERMINAL IN
A WIRELESS COMMUNICATIONS NETWORK****Inventor:** BELCEA JOHN [US] **Applicant:** MESHNETWORKS INC
[US]; BELCEA JOHN [US]**EC:** H04W64/00; G01S5/02R1; **IPC:** G01S5/00; G01S5/02;
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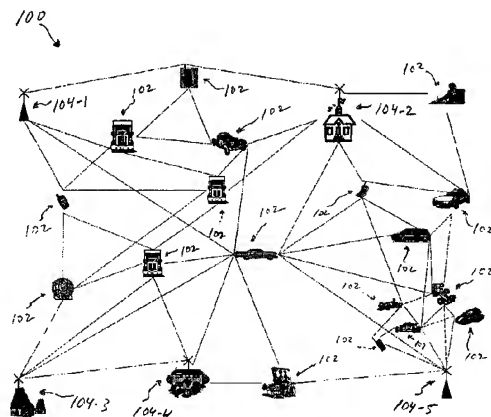
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(57) Abstract: A system and method for computing the location of a mobile terminal (102) in a wireless communications network (100), such as an ad-hoc wireless communications network. In particular, the system and method estimates the location of a mobile terminal (102) in a wireless communications network (100), such as an ad-hoc terrestrial wireless communications network, based on estimated distances to a plurality of terrestrial reference terminals (104) using error minimizing techniques, such as those based on Gauss's postulate. In doing so, the system and method estimate a respective distance from the mobile terminal (102) from the reference terminals (104), calculate a respective simulated pattern (C1-C5), such as a sphere or circle, about each of the respective reference terminals (104) based on the respective distance from the terminal (102) to each respective reference terminal (104) and the respective locations of the respective reference terminals (104), estimates a location at which each of the simulated patterns (C1-C5) intersect each other, and identifies the estimated location as representing the location of the terminal (102).

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A SYSTEM AND METHOD FOR COMPUTING THE LOCATION OF A
MOBILE TERMINAL IN A WIRELESS COMMUNICATIONS NETWORK

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to a system and method for computing the location of a mobile terminal in a wireless communications network, such as an ad-hoc wireless communications network. More particularly, the present invention relates to a system and method for computing the location of a mobile terminal in a wireless communications network, such as an ad-hoc terrestrial wireless communications network, based on estimated distances to a plurality of terrestrial reference terminals using error minimizing techniques, such as Gauss's postulate.

Description of the Related Art:

[0002] Wireless communications networks, such as mobile wireless telephone networks, have become increasingly prevalent over the past decade. These wireless communications networks are commonly referred to as "cellular networks", because the network infrastructure is arranged to divide the service area into a plurality of regions called "cells".

[0003] Specifically, a terrestrial cellular network includes a plurality of interconnected base stations that are distributed geographically at designated locations throughout the service area. Each base station includes one or more transceivers that are capable of transmitting and receiving electromagnetic signals, such as radio frequency (RF) communications signals, to and from user terminals, such as wireless telephones, located in its coverage area. The communications signals include, for example, voice data that has been modulated according to a desired modulation technique and transmitted as data packets. As can be appreciated by one skilled in the art, the transceiver and user terminals transmit and receive the data packets in multiplexed format, such as time-division multiple access (TDMA) format, code-division multiple access (CDMA) format, or frequency-division multiple access

(FDMA) format, which enables a single transceiver at the base station to communicate simultaneously with several user terminals in its coverage area.

[0004] In recent years, a type of mobile communications network known as an “ad-hoc” network has been developed for use by the military. In this type of network, each user terminal is capable of operating as a base station or router for the other user terminals, thus eliminating the need for a fixed infrastructure of base stations. Details of an ad-hoc network are set forth in U.S. Patent No. 5,943,322 to Mayor, the entire content of which is incorporated herein by reference.

[0005] More sophisticated ad-hoc networks are also being developed which, in addition to enabling user terminals to communicate with each other as in a conventional ad-hoc network, further enable the user terminals to access a fixed network and thus communicate with other user terminals, such as those on the public switched telephone network (PSTN), and on other networks such as the Internet. Details of these types of ad-hoc networks are described in U.S. patent application Serial No. 09/897,790 entitled “Ad Hoc Peer-to-Peer Mobile Radio Access System Interfaced to the PSTN and Cellular Networks”, filed on June 29, 2001, and in U.S. patent application Serial No. 09/815,157 entitled “Time Division Protocol for an Ad-Hoc, Peer-to-Peer Radio Network Having Coordinating Channel Access to Shared Parallel Data Channels with Separate Reservation Channel”, filed on March 22, 2001, the entire content of both of said patent applications being incorporated herein by reference.

[0006] In either conventional wireless communications networks, or in ad-hoc wireless communications networks, it may be necessary or desirable for a user terminal to be capable of knowing or determining its geographic location. Different types of location determining services and techniques for wireless communications networks are described in a publication by Nokia which can be found on the Nokia website at “www.nokia.com/press/background/pdf/mlbs.pdf”, the entire contents of which being incorporated herein by reference. In particular, the Nokia document states that location identification services are currently provided in wireless communications networks based on three major technologies. One of these

technologies uses cell identification combined with Round Trip Time (RTT), Timing Advance (TA) and Measured Signal level (RX level), Time Difference of Arrival (TDOA) and Angle Of Arrival (AOA) techniques, the details of which can be appreciated by one skilled in the art. A second technology uses cellular signal timing based methods for code division multiple access (CDMA) and wideband code division multiple access (WCDMA). The third technology described in the Nokia document employs Global Positioning System (GPS) techniques.

[0007] Another list of methods and techniques currently used in the wireless communications industry for providing location services can be found at “www.911dispatch.com/911_file/location_tech.html”, the entire contents of which being incorporated herein by reference. Although the GPS technique is the last technique mentioned in this list, it generally is viewed as being more accurate than all of the other methods. Further details and descriptions of GPS based methods are set forth in a publication by J. J. Spilker Jr. entitled “Satellite Constellation and Geometric Dilution of Precision” in “GPS - Theory and Applications”, American Institute of Astronautics, Inc., 1996, in a publication by P. Axelrad et al. entitled “GPS Navigation Algorithms” in “GPS - Theory and Applications”, American Institute of Astronautics, Inc., 1996, in a publication by Bradford W. Parkinson entitled “GPS Error Analysis” in “GPS - Theory and Applications”, American Institute of Astronautics, 1996, and in a publication by N. Ashby et al. “Introduction to Relativistic Effects on the Global Positioning System” in “GPS - Theory and Applications”, American Institute of Astronautics, 1996, the entire contents of each of these publications being incorporated herein by reference.

[0008] Despite the fact that the GPS technique has been in use for a considerable duration of time and most of the world’s navigation relies on this technique, the GPS technique is very susceptible to errors in measurement. Therefore, the GPS technique is capable of providing location determination results with very high accuracy only after performing a relative large number of measurements to remove such errors. A description of the shortcomings of GPS is set forth in a document by IMA entitled “Mathematical Challenges in Global Positioning Systems (GPS)” which can be found

at “www.ima.umn.edu/gps”, the entire contents of this document being incorporated herein by reference. Certain other tests also demonstrate that the GPS technique is unsuitable for terrestrial-based networks.

[0009] In addition, other methods and techniques which do not use GPS satellites for determining mobile station locations in a wireless communications network typically require that the signal from the mobile station is received at at least two cell sites that can measure and process the delay between signals arrival, identify the direction of the signal based on “path signature” and determine the distance between mobile station and the cell towers. In all of these methods, the processing of the information is executed in a designated central processing unit (CPU) which is typically located at a cell tower next to the base station (BTS). Also, most of these methods were designed to comply with E911 requirements without requiring that excessive modifications be made to existing wireless communications systems. Examples of other location determining techniques are set forth in a document by CERN - European Organization for Nuclear Research, which can be found at “rkb.home.cern.ch/rkb/ANI16pp/node98.html#SECTION00098000000000000000”, in a document by Wendy J Woodbury Straight entitled “Exploring a New Reference System”, which can be found at “menstorsoftwareince.com/profile/newref.html”, and in a document entitled “An Introduction to SnapTrac Server-Aided GPS Technology”, which can be found at “www.snaptrack.com/pdf/ion.pdf”, the entire contents of each of these documents being incorporated herein by reference.

[0010] Accordingly, a need exists for an improved system and method for determining the location of a mobile user terminal in a wireless communications network that substantially eliminate the drawbacks associated with existing location determining systems and methods, such as GPS.

SUMMARY OF THE INVENTION

[0011] An object of the present invention is to provide an improved system and method for computing the location of a mobile terminal in a wireless communications network, such as an ad-hoc wireless communications network.

[0012] Another object of the present invention is to provide a system and method for computing the location of a mobile terminal in a wireless communications network, such as an ad-hoc terrestrial wireless communications network, based on estimated distances to a plurality of terrestrial reference terminals using error minimizing techniques.

[0013] These and other objects are substantially achieved by providing a system and method for determining the location of a terminal in a wireless communications network. The system and method perform the operation of receiving respective signals from each of a plurality of reference terminals at the terminal, with each respective signal including information representing a location of its respective reference terminal. Specifically, the terminal receives the respective signals from at least four reference terminals, which can be terrestrial terminals. Also, the wireless communications network can be an ad-hoc wireless communications network, with the terminal and reference terminals being adapted to operate in the ad-hoc wireless communications network. The system and method further perform the operations of estimating a respective distance from the terminal to each of the reference terminals based on the respective signals received at the terminal, calculating a respective simulated pattern, such as a sphere or circle, about each of the respective reference terminals based on the respective distance from the terminal to each respective reference terminal and the respective locations of the respective reference terminals, estimating a location at which each of the simulated patterns intersect each other, and identifying the estimated location as representing the location of the terminal. When estimating the respective distances from the terminal to the reference terminals, the

system and error can perform error minimizing techniques, such as those in accordance with Gauss's postulate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] These and other objects, advantages and novel features of the invention will be more readily appreciated from the following detailed description when read in conjunction with the accompanying drawings, in which:

[0015] Fig. 1 is a conceptual block diagram of an example of an ad-hoc packet-switched wireless communications network employing a system and method for computing the location of a mobile terminal in the network according to an embodiment of the present invention; and

[0016] Fig. 2 is a conceptual block diagram illustrating an example of a technique that a mobile terminal in the network shown in Fig. 1 can use to determine its location according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] Fig. 1 is a conceptual block diagram illustrating an example of an ad-hoc packet-switched wireless communications network 100 employing an embodiment of the present invention. Specifically, the network 100 includes a plurality of user terminals 102 which, as indicated, can be configured hand-held devices for use by an individual, and can also be deployed in homes or offices, or in vehicles such as automobiles, trucks and the like. User terminals 102 can be referred to generally as "mobile terminals" 102, because they can be mobile or stationary at any given time.

[0018] As further indicated, network 100 includes a plurality of fixed terminals 104-1 through 104-5 (referred to generally as fixed terminals 104), which always are stationary. These types of terminals can be fixed routers for routing data packets to other mobile terminals 102 or fixed terminals 104. Also, certain fixed terminals can be configured as intelligent access points (IAPs) for providing the user terminals 102

with access to a fixed network (not shown) which includes, for example, a core local access network (LAN) and a plurality of servers and gateway routers, to thus provide the mobile terminals 102 with access to other networks, such as the public switched telephone network (PSTN), other ad-hoc networks, and the Internet, to name a few. Although this example shows the network 100 as including five fixed terminals 104, the network 100 naturally would have as many fixed terminals 104 as deemed appropriate to adequately service the mobile terminals 102.

[0019] The mobile terminals 102 and fixed terminals 104 are capable of communicating with each other directly, or via one or more other mobile terminals 102 and/or fixed terminals 104 operating as a router or routers for data packets being sent between mobile terminals 102 or fixed terminals 104, as described in U.S. Patent No. 5,943,322 to Mayor and in U.S. patent application Serial Nos. 09/897,790 and 09/815,157, referenced above. That is, each mobile terminal 102 and fixed terminal 104 includes a transceiver which is capable of receiving and transmitting signals, such as packetized data signals, to and from itself under the control of a controller. The packetized data signals can include, for example, voice, data or multimedia.

[0020] Each mobile terminal 102 and fixed terminal 104 further includes a memory, such as a random access memory (RAM), that is capable of storing, among other things, routing information pertaining to itself and other mobile terminals 102 and fixed terminals 104 in the network 100. The mobile terminals 102 and fixed terminals 104 exchange their respective routing information, referred to as routing advertisements or routing table information, with each other via a broadcasting mechanism periodically, for example, when a new mobile terminal 102 enters the network 100, or when existing mobile terminals 102 in the network 100 move. A mobile terminal 102 or fixed terminal 104 will broadcast its routing table updates, and nearby mobile terminals 102 and fixed terminals 104 will only receive the broadcast routing table updates if within radio frequency (RF) range of the broadcasting mobile terminal 102 or fixed terminal 104.

[0021] Each of the mobile terminals 102 and fixed terminals 104 that receive the routing table information from the broadcasting mobile terminal 102 or fixed terminal

104 can store all or a relevant portion of that routing table information in their respective memory. Typically, each mobile terminal 102 and fixed terminal 104 will perform a pruning operation to reduce the amount of routing table information that it stores in its memory as can be appreciated by one skilled in the art. It is also noted that when a mobile terminal 102 or fixed terminal 104 broadcasts the routing table information to its neighboring mobile terminals 102 and/or fixed terminals 104, the broadcasting mobile terminal 102 or fixed terminal 104 can include routing table information pertaining to some or all of its neighboring mobile terminals 102 and/or fixed terminals 104 that it has previously received from them and has stored in its memory. Accordingly, a mobile terminal 102 or fixed terminal 104 receiving the broadcast routing table information from a mobile terminal 102 or fixed terminal 104 also receives some information pertaining to the routing capabilities of the neighbors of that other mobile terminal 102 or fixed terminal 104.

[0022] In addition, mobile terminals 102 and fixed terminals 104 in the network 100 have the capability to measure with high precision the propagation time of radio signals between the terminals 102 and 104. Based on this information and known positions of fixed terminals, such as IAPs, routers and other network members, one mobile terminal 102 can compute its geographic location coordinates with high accuracy as will now be described.

[0023] In the network 100, the fixed terminals 104 have their locations measured at high accuracy at the time of their installation in the network 100. From time to time, the fixed terminals 104 broadcast location messages communicating their location to other mobile terminals 102 and fixed terminals 104 within their RF range. Each mobile terminal 102 that can receive the location messages from at least four other fixed terminals 104 or mobile terminals 102 can compute their positions. Also, the accuracy of the location calculation increases as the number of received location messages increases. As can be appreciated by one skilled in the art, in order for a mobile terminal 102 to compute its own position, the mobile terminal 102 must know the propagation time of the radio signals received from a particular fixed terminals 104 or mobile terminals 102, and the coordinates of that fixed or mobile terminal that

has transmitted the signals. A method for accurately measuring the signal propagation time is described in copending U.S. patent application Serial No. 09/815,157, referenced above. Once a mobile terminal 102 has computed its position, it can broadcast a location message communicating its position to other members of the network 100, such as to other mobile terminals 102 and fixed terminals 104. The information can thus be used by other mobile terminals 102 to enable them to compute their locations.

[0024] An example in which a mobile terminal 102 in a car (identified specifically as mobile terminal 102-1) can determine its own location using a system and method according to an embodiment of the present invention will now be described in more detail with reference to Fig. 2. As indicated in this example, mobile terminal 102-1 can receive location messages transmitted by all five fixed terminals 104-1 through 104-5 and can determine the respective distances to each of the fixed terminals 104-1 through 104-5. Based on the distance to each of these five fixed terminals 104-1 through 104-5, the calculations performed by the mobile terminal 102-1 simulate a respective pattern (e.g., a sphere or circle) C1 through C5 around each of the fixed terminals 104-1 through 104-5 based on the respective distances to each of the respective fixed terminals 104-1 through 104-5. For illustrative purposes, Fig. 2 shows the patterns C1 through C5 as being circular shaped. However, in actuality, the patterns are three-dimensional and thus spherical in shape to take into account longitude, latitude and altitude. The calculation then attempts to determine the location at which these five circles intersect. However, because the measurements such as the distances to the fixed terminals 104-1 and 104-5 and the information representing the locations of fixed stations 104-1 through 104-5 can be affected by unknown errors, the intersection of the five patterns C1 through C5 may not exist. Accordingly, the technique performed by the mobile terminal 102-1 according to an embodiment of the present invention estimates the most probable location of the mobile terminal 102-1.

[0025] As will now be demonstrated by the following equations and explanation, the technique that the user terminal 102-1 performs to determine its location

according to an embodiment of the present invention is based on Gauss's postulate which holds that the most probable approximation of a measure is that which minimizes the sum of square of errors. The mathematical formulation of the technique takes into account that mobile terminal 102-1 has recorded known positions (x_i, y_i, z_i) of n neighbors (e.g., n fixed terminals 104) and the respective distance r_i to each of them. The technique thus calculates the position of the mobile terminal 102-1 as a point of coordinates (x, y, z) .

[0026] If measurements are not affected by any error and the computation is correct, the position (x, y, z) of the mobile terminal 102-1 must fulfill the system of n equations:

$$\sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} - r_i = 0 \text{ for } i=1, 2, \dots, n \quad (1)$$

[0027] Each member of equation (1) can be represented graphically as a sphere centered in (x_i, y_i, z_i) with radius r_i . In the example shown in Fig. 2, sphere C1 (shown in two-dimensions as a circle) surrounding fixed terminal 104-1 would have its coordinates centered at (x_1, y_1, z_1) with radius r_1 being the distance from fixed terminal 104-1 to mobile terminal 102-1, sphere C2 surrounding fixed terminal 104-2 would have its coordinates centered at (x_2, y_2, z_2) with radius r_2 being the distance from fixed terminal 104-2 to mobile terminal 102-1, and so on. Ideally, all n spheres C1 through C5 must be intersecting in one point, namely, the location of the mobile terminal 102-1 performing the computation. However, in reality, because r_i and (x_i, y_i, z_i) are affected by measurement errors as discussed above, these spheres C1 through C5 will not all intersect in one point, but will pass close to the real position of the mobile terminal 102-1.

[0028] The distances from a point of coordinates (x, y, z) to all n supporting terminals can be computed in accordance with equation (2) as follows:

$$\rho_i(x, y, z) = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} \text{ for } i=1, 2, \dots, n \quad (2)$$

[0029] For any point of coordinates (x, y, z) , the differences between the computed distances ρ_i and the measured distances r_i are determined in accordance with equation (3) :

$$\varepsilon_i(x, y, z) = \rho_i(x, y, z) - r_i \quad \text{for } i=1, 2, \dots, n \quad (3)$$

[0030] In the graphical representation shown in Fig. 2, the system of equation (3) provides the distance of the point of coordinates (x, y, z) to each of the n spheres. In equation (3) r_i are measured numerical values, while ρ_i are functions of the point coordinates (x, y, z) . It means that the errors ε_i are also functions of the same coordinates.

[0031] The sum of squares of errors ε_i becomes also a function of mobile station position as presented in equation (4)

$$E(x, y, z) = \sum_{i=1}^n \varepsilon_i^2(x, y, z) \quad (4)$$

[0032] In accordance with Gauss's postulate, the most probable position of the mobile station $E(x, y, z)$ is the one that minimizes the value of the $E(x, y, z)$ function. In the point (x, y, z) where the function $E(x, y, z)$ has the minimum value, all partial derivative must be zero. After writing the equations for finding the point where the derivative are zero and considering linear approximations of the quadratic equations, the following relationships can be obtained in the system of equations (5) as follows:

$$\begin{aligned}
& \sum_{i=1}^n \left(\frac{r_i}{\rho_i(x_0, y_0, z_0)} \left(\left(\frac{x_0 - x_i}{\rho_i(x_0, y_0, z_0)} \right)^2 - 1 \right) + 1 \right) \delta x + \sum_{i=1}^n \left(\frac{(x_0 - x_i)(y_0 - y_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta y + \sum_{i=1}^n \left(\frac{(x_0 - x_i)(z_0 - z_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{x_0 - x_i}{\rho_i(x_0, y_0, z_0)} \right) \\
& \sum_{i=1}^n \left(\frac{(y_0 - y_i)(x_0 - x_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta x + \sum_{i=1}^n \left(\frac{r_i}{\rho_i(x_0, y_0, z_0)} \left(\left(\frac{y_0 - y_i}{\rho_i(x_0, y_0, z_0)} \right)^2 - 1 \right) + 1 \right) \delta y + \sum_{i=1}^n \left(\frac{(y_0 - y_i)(z_0 - z_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{y_0 - y_i}{\rho_i(x_0, y_0, z_0)} \right) \\
& \sum_{i=1}^n \left(\frac{(z_0 - z_i)(x_0 - x_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta x + \sum_{i=1}^n \left(\frac{(z_0 - z_i)(y_0 - y_i)r_i}{\rho_i^3(x_0, y_0, z_0)} \right) \delta y + \sum_{i=1}^n \left(\frac{r_i}{\rho_i(x_0, y_0, z_0)} \left(\left(\frac{z_0 - z_i}{\rho_i(x_0, y_0, z_0)} \right)^2 - 1 \right) + 1 \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{z_0 - z_i}{\rho_i(x_0, y_0, z_0)} \right)
\end{aligned}
\tag{5}$$

[0033] The system of equations (5) has three unknown variables δx , δy , δz , which are the corrections to be applied to the current approximation (x_0, y_0, z_0) of the mobile terminal for improving its position estimate. This means that after estimating the mobile terminal position (x_0, y_0, z_0) , the system of equations (5) is used for computing the corrections δx , δy and δz . The improved estimated position is then computed in accordance with the following equations (6)

$$\begin{aligned}
x'_0 &= x_0 + \delta x \\
y'_0 &= y_0 + \delta y \\
z'_0 &= z_0 + \delta z
\end{aligned}
\tag{6}$$

[0034] The system of equations (5) is used again for finding new corrections δx , δy , δz . This process continues iteratively until the computed corrections are smaller than the accepted error. As can be appreciated by one skilled in the art, Gauss's "Law of Propagation of Errors" gives the value of standard deviation of errors σ of a multiple variable function in relation with standard deviation of errors for each variable σ_x , σ_y , σ_z is as follows:

$$\sigma^2 = \left(\frac{\partial f}{\partial x} \right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y} \right)^2 \sigma_y^2 + \left(\frac{\partial f}{\partial z} \right)^2 \sigma_z^2
\tag{7}$$

[0035] Another expression of standard deviation of distance errors derived from equation (4) is :

$$\sigma^2 = \frac{E(x, y, z)}{n-3} \quad (8)$$

[0036] In this equation, the nominator $n-3$ represents the number of degree of freedom of the system of data. The term $E(x, y, z)$ is defined in equation (4) above. Equation (8) thus provides the value of σ^2 as function of (x, y, z) . Since the position (x, y, z) of the mobile is computed to minimize $E(x, y, z)$, the computed position of mobile minimizes also the value of σ^2 when $n > 3$.

[0037] As stated above, the measured elements are the distances from the mobile terminal 102-1 to all other reference stations, which in this example are the fixed terminals 104-1 through 104-5. By replacing the partial derivative in (7) with distance derivatives, the following equation is obtained:

$$\sigma^2 = \left(\frac{x-x_i}{\rho_i} \right)^2 \sigma_x^2 + \left(\frac{y-y_i}{\rho_i} \right)^2 \sigma_y^2 + \left(\frac{z-z_i}{\rho_i} \right)^2 \sigma_z^2 \text{ for } i=1, 2, \dots, n \quad (9)$$

[0038] In this equation, the terms in parenthesis represent the unitary vectors of directions from the mobile station 102-1 to all supporting stations which, in this example, are fixed terminals 104-1 through 104-5. By replacing (x, y, z) with the coordinates (x_0, y_0, z_0) of mobile terminal 102-1 and σ^2 with its value computed in (7), a system of n linear equations with three unknown variables σ_x^2 , σ_y^2 and σ_z^2 is obtained, which represents the standard deviations along axes.

$$\frac{E(x, y, z)}{n-3} = \left(\frac{x_0-x_i}{\rho_i} \right)^2 \sigma_x^2 + \left(\frac{y_0-y_i}{\rho_i} \right)^2 \sigma_y^2 + \left(\frac{z_0-z_i}{\rho_i} \right)^2 \sigma_z^2 \text{ for } i=1, 2, \dots, n \quad (10)$$

[0039] The least squares method (LSM) is used for solving this system and finding the standard deviation along each axis. When the reference stations (fixed

terminals 104-1 through 104-5) are very far from the mobile terminal 102-1, the measured distance r_i and the approximated distance ρ_i are very high. In a GPS system, for example, the distance to satellites is about 26,000 Km, which means that:

$$\boxed{\frac{r_i}{\rho_i(x_0, y_0, z_0)}} \approx 1 \text{ for } i=1, 2, \dots, n \quad (11)$$

[0040] As indicated, equation (11) is not a real equality. However, if ρ_i is approximated with an error of, for example, 10 Km, the left-hand side of equation (11) will equal 1 taken to the third decimal place. For instance, assuming that the measured distance to the satellite is 26152 Km, and based on a current approximation of the mobile position, the computed distance is off by 10 Km, then the computed distance is 26142 Km. When these values are entered into equation (11) as follows, the result is

$$\frac{r}{\rho(x, y, z)} = \frac{26152}{26142} = 1.0004$$

[0041] or almost one. This demonstrates that the technique according to the embodiment of the present invention as described above can be used in a GPS scenario. In other words, the technique described above is more general than the GPS technique, and the GPS technique can be derived from this method under special conditions, such as very long distances to reference satellites. Accordingly, the system of equations (11) can be used to obtain the following system of equations:

$$\begin{aligned}
 & \left[\sum_{i=1}^n \left(\frac{x_0 - x_i}{\rho_i(x_0, y_0, z_0)} \right)^2 \delta x + \sum_{i=1}^n \left(\frac{(x_0 - x_i)(y_0 - y_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta y + \sum_{i=1}^n \left(\frac{(x_0 - x_i)(z_0 - z_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{x_0 - x_i}{\rho_i(x_0, y_0, z_0)} \right) \right. \\
 & \left[\sum_{i=1}^n \left(\frac{(y_0 - y_i)(x_0 - x_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta x + \sum_{i=1}^n \left(\frac{(y_0 - y_i)^2}{\rho_i(x_0, y_0, z_0)} \right) \delta y + \sum_{i=1}^n \left(\frac{(y_0 - y_i)(z_0 - z_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{y_0 - y_i}{\rho_i(x_0, y_0, z_0)} \right) \right. \\
 & \left[\sum_{i=1}^n \left(\frac{(z_0 - z_i)(x_0 - x_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta x + \sum_{i=1}^n \left(\frac{(z_0 - z_i)(y_0 - y_i)}{\rho_i^2(x_0, y_0, z_0)} \right) \delta y + \sum_{i=1}^n \left(\frac{(z_0 - z_i)^2}{\rho_i(x_0, y_0, z_0)} \right) \delta z = - \sum_{i=1}^n \left((\rho_i(x_0, y_0, z_0) - r_i) \frac{z_0 - z_i}{\rho_i(x_0, y_0, z_0)} \right)
 \end{aligned}
 \tag{12}$$

[0042] It is noted that the publication by J.J. Spilker, referenced above, presents the system of equations (12) as a preferred method for computing the positions of mobile GPS receivers. This suggests that the technique described above can also be used for computing the location of mobile GPS receivers, and not only to compute the location of mobile terminals of a terrestrial-based systems.

[0043] As can also be appreciated from the above, the technique according to an embodiment of the present invention measures the distances of a mobile terminal to a plurality of terrestrial fixed terminals and computes the location of the mobile terminal based on those distances. On the other hand, GPS methods measure the distances from a mobile station to a set of satellites and compute the location of the mobile station based on these distances. Also, GPS solves the linear approximation of the multiple circles intersection, while the technique described above according to an embodiment of the present invention computes the most probable intersection point of the spheres (e.g., spheres C1 through C5) to compute the location of a mobile terminal.

[0044] Accordingly, if the technique described above were to be used in a satellite-based network in which the reference stations (e.g. satellites) are located very far from the mobile terminal, the technique would provide results similar to the GPS techniques. However, for terrestrial applications, when the reference stations (e.g., fixed stations 104-1 through 104-5) are relatively close to the mobile terminal 102-1, the GPS technique fails to provide any suitable result. Accordingly, the technique described above is far superior to GPS for determining the location of a mobile terminal in a terrestrial-based network.

[0045] Although only a few exemplary embodiments of the present invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims.

What is claimed is:

1. A method for determining the location of a terminal in a wireless communications network, comprising:

receiving respective signals from each of a plurality of reference terminals at said terminal, each said respective signal including information representing a location of its respective said reference terminal;

estimating a respective distance from said terminal to each of said reference terminals based on said respective signals received at said terminal;

calculating a respective simulated pattern about each of said respective reference terminals based on said respective distance from said terminal to each said respective reference terminal and said respective locations of said respective reference terminals; and

estimating a location at which each of said simulated patterns intersect each other, and identifying said estimated location as representing the location of said terminal.

2. A method as claimed in claim 1, wherein:

said distance estimating includes performing error minimizing calculations based on Gauss's postulate to minimize errors in estimating said respective distances.

3. A method as claimed in claim 1, wherein:

during said receiving, said terminal receives said respective signals from at least four of said reference terminals.

4. A method as claimed in claim 1, wherein:

said reference terminals are each terrestrial terminals.

5. A method as claimed in claim 1, wherein:

said network includes an ad-hoc network, and said terminal and said reference terminals are adapted to operate in said ad-hoc network.

6. A method as claimed in claim 1, wherein:
each of said patterns is spherical.

7. A system for determining the location of a terminal in a wireless communications network, comprising:

a receiver, adapted to receive respective signals from each of a plurality of reference terminals at said terminal, each said respective signal including information representing a location of its respective said reference terminal; and

a processor, adapted to estimate a respective distance from said terminal to each of said reference terminals based on said respective signals received at said terminal, calculate a respective simulated pattern about each of said respective reference terminals based on said respective distance from said terminal to each said respective reference terminal and said respective locations of said respective reference terminals, estimate a location at which each of said simulated patterns intersect each other, and identify said estimated location as representing the location of said terminal.

8. A system as claimed in claim 7, wherein:
said distance estimating includes performing error minimizing calculations based on Gauss's postulate to minimize errors in estimating said respective distances.

9. A system as claimed in claim 7, wherein:
during said receiving, said terminal receives said respective signals from at least four of said reference terminals.

10. A system as claimed in claim 7, wherein:
said reference terminals are each terrestrial terminals.

11. A system as claimed in claim 7, wherein:
said network includes an ad-hoc network, and said terminal and said reference terminals are adapted to operate in said ad-hoc network.

12. A system as claimed in claim 7, wherein:
each of said patterns is spherical.

13. A computer-readable medium of instructions for determining the location of a terminal in a wireless communications network, comprising:

a first set of instructions, adapted to estimate a respective distance from said terminal to each of a plurality of reference terminals based on respective signals received at said terminal from each of a plurality of reference terminals, each said respective signal including information representing a location of its respective said reference terminal;

a second set of instructions, adapted to calculate a respective simulated pattern about each of said respective reference terminals based on said respective distance from said terminal to each said respective reference terminal and said respective locations of said respective reference terminals; and

a third set of instructions, adapted to estimate a location at which each of said simulated patterns intersect each other, and identifying said estimated location as representing the location of said terminal.

14. A computer-readable medium of instructions as claimed in claim 13, wherein:

said distance estimating includes performing error minimizing calculations based on Gauss's postulate to minimize errors in estimating said respective distances.

15. A computer-readable medium of instructions as claimed in claim 13, wherein:

said terminal receives said respective signals from at least four of said reference terminals.

16. A computer-readable medium of instructions as claimed in claim 13, wherein:

said reference terminals are each terrestrial terminals.

17. A computer-readable medium of instructions as claimed in claim 13, wherein:

said network includes an ad-hoc network, and said terminal and said reference terminals are adapted to operate in said ad-hoc network.

18. A computer-readable medium of instructions as claimed in claim 13, wherein:

each of said patterns is spherical.

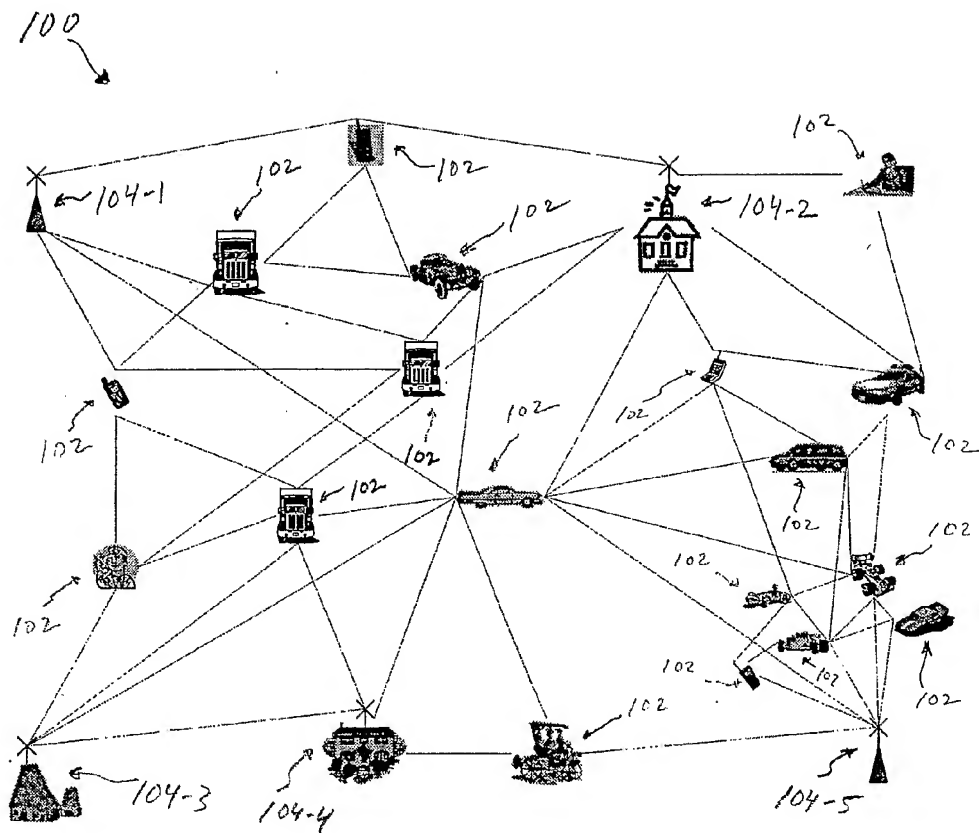


FIG. 1

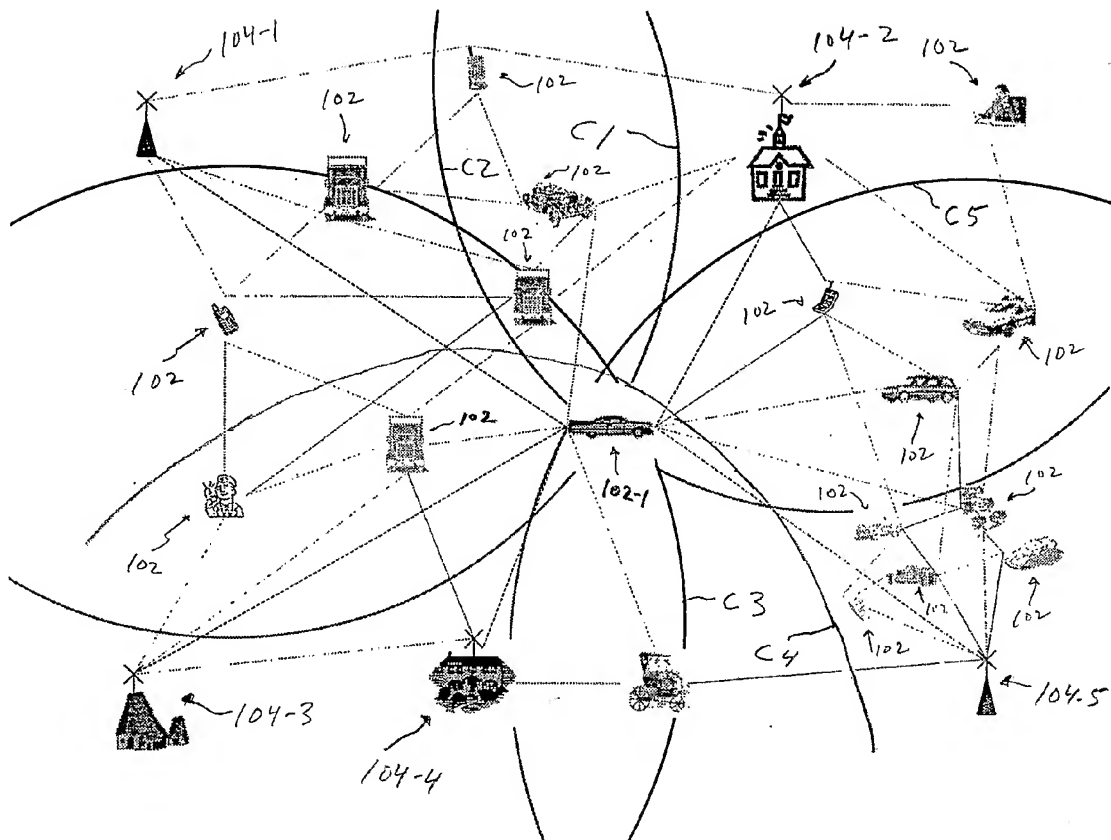


Fig. 2

INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/US02/36409

A. CLASSIFICATION OF SUBJECT MATTER IPC(7) : H04B 7/005 US CL : 455/456 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) U.S. : 455/456, 457, 517, 561, 422 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,308,073 B1 (PETTY et al) 23 October 2001, col. 2, lines 21-67 and col. 9, lines 47-67.	1, 4, 6, 7, 10, 12, 13, 16 and 18
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Y		2, 3, 5, 8, 9, 11, 14, 15 and 17
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents:		
"A"	document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"G" document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed	
Date of the actual completion of the international search 08 FEBRUARY 2003		Date of mailing of the international search report 07 MAR 2003
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer JOY K. CONTEE Telephone No. (703) 305-0149

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/36409

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,907,809 A (MOLNAR et al) 25 May 1999, col. 5, lines 55-65.	2,8 and 14
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Y	col. 2, lines 36-45	3,9 and 15
Y	BELCEA, PCT/US02/36409 Specification, page 2, lines 3-8.	5,11 and 17